A SLAM AIRFIELD MODEL FOR AIRLIFT OPERATIONS

THESIS

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Preface

The purpose of this study was to develop a small computer simulation program to model an airfield during airlift operations. Throughout the model building process, refinements were rejected that added more complexity than enlightment. It is recognized that other models are available that more faithfully model the operations of an airfield. The advantage of this model is that a broad range of information can be obtained on airfield operation with a relatively short investment of time in model setup. It was designed to provide the kind of practical information a lower level planner might be after.

Randall G. Johnson

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Abstract

This study developed a SLAM airfield model tailored for airlift operations. The model is formulated as a network and models loading, fueling, and maintenance of airlift aircraft. Only C-130, C-141, and C-5 aircraft can be considered.

The primary model inputs are aircraft input rates, and the availability of ramp space, maintenance team, load team, and k-loader resources. The output includes average groundtime, resource usage, and pallets airlifted from the airfield.

An experiment is made to identify a "best" strategy for aircraft input rates through a fixed airfield. The results show that any one of five input strategies out of 64 examined are of equal effectiveness.

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I. Introduction

Background

The United States has military commitments around the world. To meet these commitments, this country could station large standing armies throughout the world. Instead, the United States keeps the bulk of its military forces inside the country, and depends on deploying these forces overseas as needed to meet its commitments. Airlift plays an important role in the deployment of these forces. By airlift, forces can be rapidly deployed and then supplied until sea lines of communication can be established.

This country's ability to deploy and supply combat forces by air has been studied extensively since the Carter Doctrine was declared following the Soviet Union's invasion of Afghanistan in December, 1979. In this doctrine, President Carter declared that the United States would insure the western world's access to Persian Gulf oil by force, if necessary. The country's ability to enforce this doctrine depended on its ability to quickly airlift forces to the region. The studies showed that the United States did not have enough airlift to move heavy armored units quickly and that it would take weeks to move even light infantry divisions.

Since then, more studies have been made on how to schedule aircraft loads more effectively, and how to improve airlift capability by acquiring more aircraft such as the C-17, C-5, and Boeing 747.

These studies and the debates over them will continue. However, regardless of the type aircraft in the fleet or the cargo carried on them, airlift effectiveness is maximized by keeping fully loaded aircraft in the air as much as possible. This implies that traffic flow on an airfield is important in an airlift operation.

For example, during the Arab-Israeli War of 1973, the United States rushed critical supplies from 29 bases in this country to Tel Aviv by way of Lajes in the Azores. Since Lajes had to support aircraft going to Israel and returning to the United States, its capability to service and dispatch aircraft was the limiting factor in the airlift to Israel (Ref 3:p. 9). It is important, then, to study the flow of aircraft on an airfield and determine an airfield's capacity to support airlift operations. Planners would then be able to make more efficient use of airlift resources by keeping the aircraft in the air as much as possible.

Problem Statement

Airlift planners need a user friendly model to allow them to study the flow of airlift aircraft through an airfield and determine the capacity of that airfield to support airlift

operations. Besides determining the airfield capacity, the model should provide use rate information on all important aspects of the airfield.

Research Objective

The objective is to find or develop a user friendly model to describe airfield output and the usage of important elements on the airfield. For this research, a user friendly model will have the following characteristics:

1) Easily understood structure.

2) Short model setup time.

The important elements that should be modeled are aircraft fueling, loading, and maintenance.

Literature Review

This literature review is divided into two parts. The first part outlines previous studies that were examined in the effort to find a model that meets the research objective. The second part outlines possible approaches to use in developing a model to meet the research objective.

Previous Studies. This section will outline four models that are related to the problem and compare them to the requirements of the research objective. The first model to be examined is the M-14 that was developed by the Operations Research Section of Headquarters Military Airlift Command. This model simulates the movement of airlift aircraft worldwide, and includes over 400 airfields (Ref 10). The factors

the model considers are parking, fueling, loading, and maintenance. The strong point of the model is that it studies airlift as a single worldwide system. When compared to the research objective, however, it has some weaknesses. First, it is not user friendly. The model takes three to four months setup time prior to each use and must be run on the Cray computer at Kirtland AFB, NM because the model is so large (Ref 10). As mentioned before, the model can consider over 400 airfields at once and does not look at a single airfield in isolation. Although elements of the model could be useful in developing a model to meet the research objective, it does not, by itself, meet that objective.

The second model is a runway simulation model by M. J. Atack. This model considered weather, air traffic control procedures, and aircraft performance. This model did not have the long setup time required by the M-14 model, requiring only one to two man days to set up a computer run (Ref 1). Although it models activity on a runway in great detail, it does not model fueling, loading, or maintenance of aircraft. These factors are all essential elements of an airfield in airlift operations. As with the M-14 model, certain elements of the Atack runway model could be useful in developing a model to meet the research objective, but, the model, by itself, does not meet that objective.

The third model examined was an airfield simulation model developed by the Federal Aviation Administration (FAA).

This model directly addressed the issue of airfield capacity. The model considered aircraft landing, taxiing, parking, servicing, and takeoff. The model, however, was concerned mostly with passenger operations, and did not model fueling, loading, and maintenance as separate components of servicing (Ref 2:p. III-9). The research objective requires that these important elements be modeled separately.

Cargo requires more equipment for loading than passengers. The equipment available for loading and fueling is an important element of an airlift operation. Again, this model has many elements useful in developing a model, but, by itself, does not meet the research objective.

The model that comes closest to meeting the research objective was a tactical airbase simulation model built by Major Mann and Lt. Shook (Ref 5). The model considers the loading of weapons for fighters. This process is analogous to loading cargo onto transport aircraft. The model also deals with maintenance and fueling of fighter aircraft. The measure of merit used in the model was sorties generated. The purpose of the model was to identify the parts of the airfield that would be vulnerable to attack and, hence, decrease the measure of merit. Although this model deals with many of the same elements of airfield operation as are present during airlift operations, it is still oriented to a fighter base and does not meet the research objective.

None of the models examined met the requirements of the

research objective, although all of them had parts that would be useful in developing such a model.

Possible Approaches. This section outlines general approaches found in the literature that were examined for possible use.

One way of looking at the problem would be network theory. The goal would be to maximize the number of aircraft going through the network. A simple network with a single source and sink could be established as in Fig. 1.1.

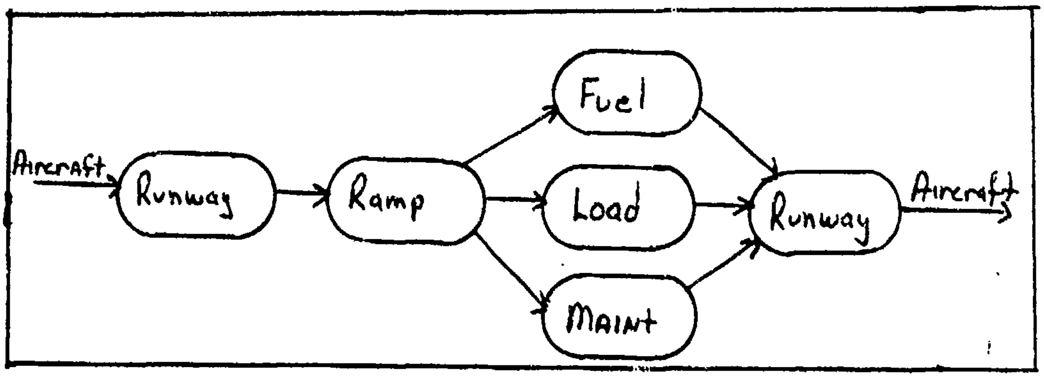

Fig. 1.1 Network Formulation

The capacity of the arcs would be determined by the resources available. For example, if six fuel trucks could refuel two C-141s in an hour, the flow capacity on the arc from the node labeled ramp to the one labeled load would be three C-141s per hour. The capacity of the network could be found by solving the maximal flow problem for the network. The limiting factor would be the arc that reaches capacity first.

Networks have been used to study transportation systems (Ref 4:232). However, the formulation outlined above seems to stretch a network beyond its normal use. in a typical net-

work, nodes and branches represent physical structures such as intersections and pumping stations or roads and pipes (Ref 4:234). In Fig. 1.1, only nodes Runway and Ramp, and the branch between them represent such physical structures.

This method has other shortfalls. First, a different network would be needed for each type of aircraft. Although six fuel trucks may be able to refuel three C-141s per hour, they might not be able to refuel three C-5s per hour. Second, the need for maintenance is not a certainty and a network cannot be used to deal with this stochastic process.

Another method of examining the problem could be through the use of the queuing theory. The aircraft would enter the system, be served by the servers, and then exit the system. The system would be the airfield, while the servers would be the fuel trucks, load crews, and other aspects of the airfield operation. A single queue would be unsatisfactory since it would not allow the user to determine what element or policy of the airfield was limiting the capacity. A type of queuing system that would model the airfield more effectively is the Jackson Network which is a network of queues (Ref 4). In this case, each queue in the network would represent a different aspect of airfield operation. An example of a Jackson Network queuing system for an airfield is shown in Fig. 1.2. Each square represents a different queue. In this system, the resources available would be modeled by the servers in each queue. For the loading queue, a server would be a loading

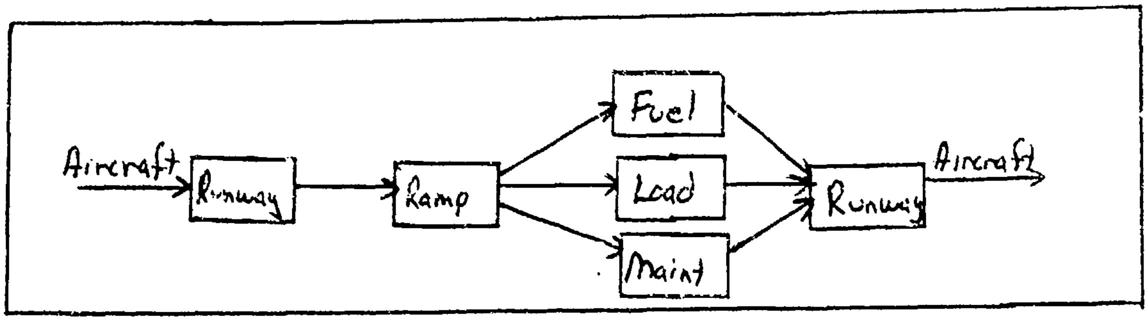

Fig. 1.2 Jackson Network for Airfield

team. The ramp queue would be modeled so that the length of the queue would be limited to the number of parking spaces available. This model would have an advantage over the network of being able to handle different types of aircraft. The different types of aircraft could be modeled by having different classes of customers allowed in the queue. A customer in this queuing system would be an aircraft. Like the network, the network of queues cannot model the uncertainty of aircraft requiring maintenance. In addition, the network of queues shown in Fig. 1.2 implies that the aircraft leaves the ramp queue to go the fuel queue. In reality, the aircraft remains in the ramp queue until it departs the airfield. This interaction between queues cannot be modeled using queuing or network theory alone. Queuing theory has been used to study transportation service systems such as aircraft waiting to takeoff and land from a runway (Ref 4:407). However, an assumption in most queuing theory is that the system is in steady state (Ref 4:405). An airfield may never reach steady state depending on the aircraft input rate and airfield resources.

The final method to be examined is simulation. The flexibility of simulation is its chief advantage. Simulation allows each of the elements of the airfield to be modeled by itself (Ref 6:p. 4). This avoids the problems that the interaction of the elements caused in the other techniques. The simulation model would look much like the network and queuing models, since the operation of an airfield can be modeled using these constructs. With simulation, information can be gathered at each node concerning items such as waiting time, number of aircraft waiting for service, or the use rate of resources. A final advantage of simulation is that it is the method of study used in all the previous works mentioned in this chapter. The useful elements of each of these studies can be used in developing a model to meet the research objective.

In conclusion, simulation is the best method to use in building a model to meet the research objective. The next section will describe the process to be used in building this model.

Methodology

The method to be followed in building will, in general, be that as outlined by Shannon. These general steps are conceptualization, computerization, verification and validation, and documentation (Ref. 9). The following paragraphs will expand these steps.

In the conceptualization phase, the important elements of the system must be defined and the relationships between them defined. In this system, the elements will be the aircraft, ramp, fueling resources, loading resources, maintenance resources, and cargo mix. The relationships between them will be outlined in the next chapter when the model is described.

In the computerization phase, the appropriate computer code to implement the conceptual model is written. In this research, the FORTRAN based SLAM (simulation language for alternative modeling) will be used (Ref 8:vii). The network portion of SLAM will be adequate to model the airfield system. An advantage of the network formulation is that the graphical presentation of the network will aid the user in understanding the structure of the model without a line-by-line study of the computer code.

The conceptual model was computerized once in Q-GERT. Some of the constructs that had to be used to implement the conceptual model using its network oriented language were awkward. In addition, the output available in Q-GERT was not flexible enough to give the information as desired. SLAM with its global variables in network models avoids the unwieldy constructs required in Q-GERT. SLAM also has more flexible graphing options than Q-GERT.

The verification process consists of testing each of the elements of the airfield separately to insure that the SLAM

code implements the conceptual model as expected. In the closely rated validation phase, the output of the model as a whole must be checked to insure it gives accurate results.

The final phase of building the simulation model will be documentation. Throughout the model building process, constructs must be built into the program to keep it user friendly. The program itself must be well documented to guide potential users through the implementation of the model.

Conclusion

This chapter has identified the need for an airfield model for airlift operations. It has examined some works that have been done in the area and shown how they do not meet the need. Next, some possible approaches for solving the problem have been studied with simulation being the preferred approach. Finally, a process to be used in building the model has been outlined. The next chapter will describe the model itself. The third chapter describes the use of the model to identify a "best" strategy for aircraft input rates through an airfield. The fourth chapter will summarize the findings of the research and suggest some avenues of further research for the model. The appendix includes a documented printout of the model.

II. System and Model Description

Introduction

The model of an airfield during airlift operation will be described in this chapter. The presentation will be divided into two parts. The first part will describe the operation of an airfield during airlift operations, while the second part will describe in detail how the process was put into computer code. The description will include the assumptions made and justification for these assumptions.

Airfield Operation

General. The physical layout of a typical airfield is shown in Fig. 2.1.

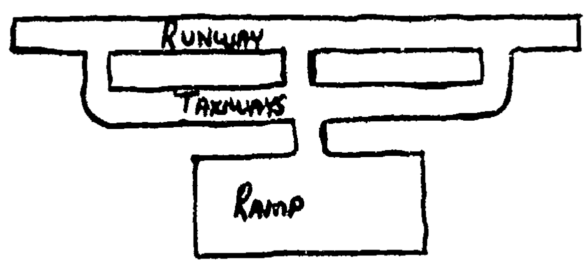

Fig. 2.1 Airfield Diagram

The runway, taxiways, and ramp are the three general parts of an airfield. Aircraft land on the runway, and, for servicing, go to the ramp via the taxiways. After servicing, the aircraft leave the ramp, taxi to the runway, and depart. This general process is common to all airfields.

It is the servicing activities on the ramp that distinguish one type of airfield operation from another. At a flight training base, only fueling and maintenance take place on the ramp, while, at a wartime fighter base, the ordinance loading is added to these two activities. At an airlift base, the additional activity would be loading. The operations of each airfield are different and need to be modeled differently.

Airlift. In an airlift operation, four servicing activities must be completed before the aircraft can depart. These activities are parking, fueling, loading, and maintenance. The parking activity requires one resource. That resource is the ramp space that is adequately stressed to withstand the weight of the aircraft that will park on it. Once the aircraft is parked and has shut down its engines, the other activities can begin.

The fueling activity requires a fuel source and a fueling team. The fuel source can be either a fuel truck or a fuel pit. A fuel truck drives alongside an aircraft, offloads some or all of its fuel to the aircraft and then returns to the fuel storage area for more fuel. A fuel pit is an access point to a network of fuel lines that run from the fuel storage to lines underneath the ramp. The lines are run beneath parking spots and can be accessed through manholes to pump fuel directly from the lines into the aircraft. The fueling team consists of the people necessary to operate the

equipment and act as safety observers.

An arriving aircraft needing maintenance requires two things to complete the activity. First, people qualified to perform the repair needed must be available. Second, the necessary tools and parts must be available for the people to finish the repairs. If an aircraft is broken, the appropriate person will be sent to the aircraft with the necessary parts and tools to repair the aircraft.

The final activity to be described will be the loading activity. There are two basic types of cargo in a military airlift. One type is palletized cargo, while the other is rolling stock. Palletized cargo is cargo that has been loaded onto an aluminum platform called a pallet which is approximately eight feet by eight feet in size. Once loaded, the cargo is secured to the pallet by cargo net and can then be handled as a single unit instead of the several pieces it was before being palletized. The pallet can be loaded onto the aircraft across rollers in the floor. Rolling stock is cargo that can move under its own power or be towed onto an aircraft. Jeeps, towed cannons, and tanks are examples of rolling stock. Once aboard an aircraft, rolling stock is chained to rings in the floor to secure it for flight.

Since there are two types of loads, the loading activity can be considered as two separate processes, using two separate resources. The first process would be loading pallets with a resource called a k-loader used. A k-loader is a flat-

bed truck with rollers on the bed that is used to transport pallets from the cargo yard to the aircraft. The capacity of a k-loader is either three or five pallets depending on its design. Once at the aircraft, the k-loader driver can adjust its height to the height of the aircraft floor. The pallets are then pushed directly from the k-loader to the aircraft. The k-loader is then free to return to the cargo yard for another load.

The second process would be loading rolling stock with its associated resource being loading teams. A loading team consists of the people necessary to position the cargo on the airplane and chain it to the floor. The rolling stock is either driven or towed into position where it is chained by the loading team. After loading the aircraft, the loading team is free to load another aircraft.

Loading, maintenance, and fueling can all occur simultaneously with some exceptions. Some types of explosives cannot be loaded and some type of maintenance cannot be done while fueling is in progress. Once the required servicing activities have been completed, the aircraft is ready to depart the airfield. The remainder of the chapter will discuss how the description of the airlift operation was modeled in computer code.

Computer Model

The description of the computer model will be split into five parts: 1) Arrival, 2) Loading, 3) Maintenance, 4)

Fueling, and 5) Departure. The loading process will be further divided into the loading of rolling stock and the loading of pallets. The description of each part will include a diagram of the SLAM network, a description of the process being modeled, a statement of the assumptions, and justification for these assumptions.

Arrival Process. The SLAM network of the arrival process is shown in Fig. 2.2. There is a CREATE node for each type of aircraft. A CREATE node generates entities within a SLAM network (Ref 8:541). In this case, the entities represent aircraft. The aircraft types are the C-130, the C-141, and the C-5. The arrival process is modeled as a poisson process. Aircraft may have been scheduled to arrive at constant time intervals, such as one every fifteen minutes, but it is assumed that factors outside the airfield system would interrupt the planned arrival process and transform it to an exponential interarrival process.

Once the aircraft entity arrives, it is routed to an ASSIGN node where it is tagged with its attributes. An ASSIGN node is used to assign values to SLAM variables at each arrival of an entity to the node (Ref 8:538). The node works like an assignment statement in FORTRAN. The attributes of an entity describe that entity. By letting attribute one represent the number of pallets an airplane can carry and then setting that attribute to a value of five, the entity can be identified as a C-130. The attributes this particular ASSIGN node

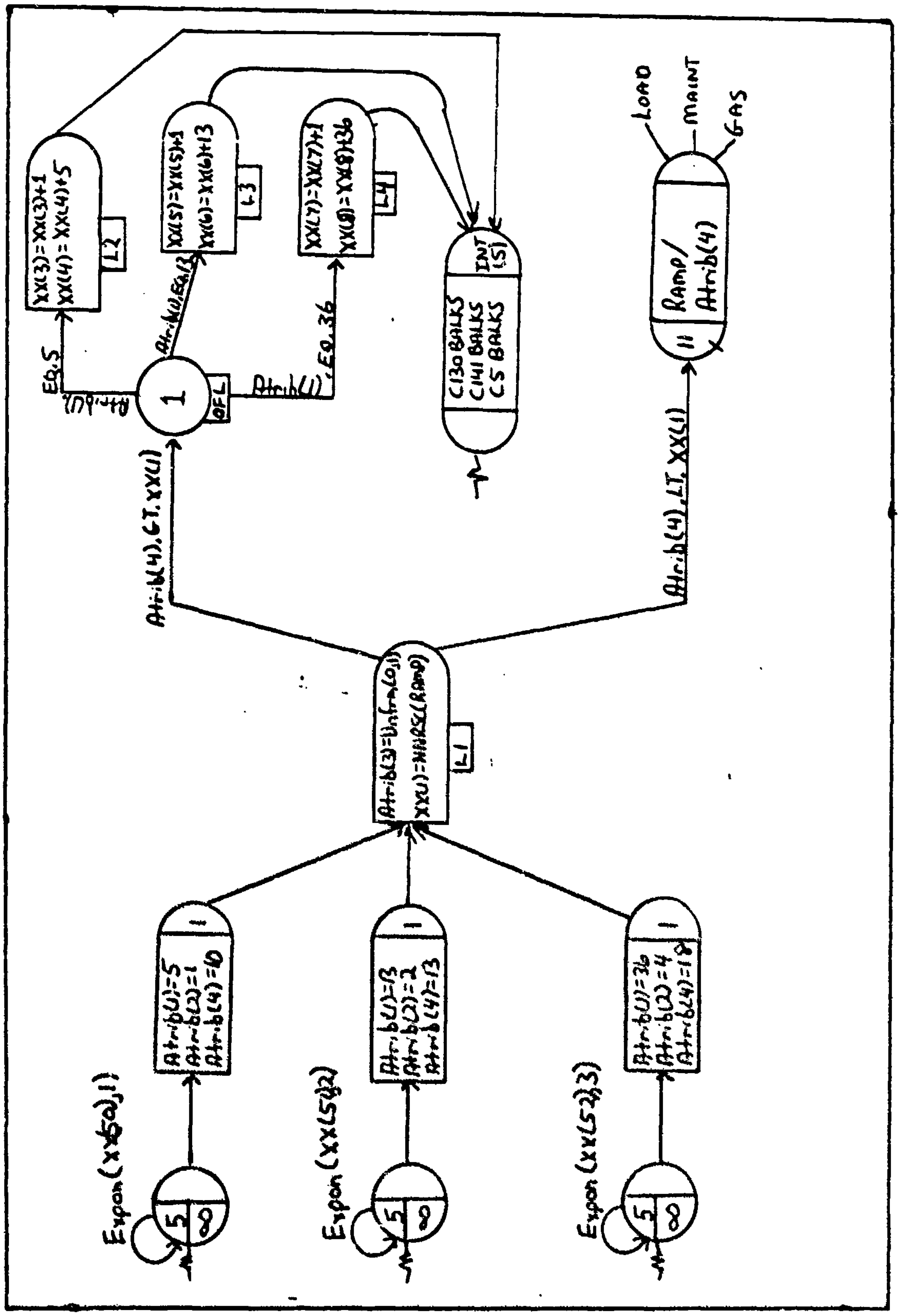

Fig. 2.2 SLAM Network - Arrival Process

sets are:

1) Atrib (1) - Pallet capacity of the aircraft.

2) Atrib (2) - Number of fuel trucks required for refueling.

3) Atrib (4) - Amount of ramp resource required.

After the aircraft entity is tagged with its characteristics, it is routed to another ASSIGN node where it is tagged with Atrib (3). This attribute will be used in the maintenance activity to determine if the aircraft requires repairs before it departs the airfield. In the same ASSIGN node, the global variable XX(1) is set equal to the amount of ramp resource remaining. As the entity leaves this ASSIGN node, the amount of ramp space the aircraft requires (Atrib (4)) is compared to the value of XX(1). If enough ramp space is available, the entity goes to the AWAIT node where it is given the ramp space it needs. The entity is then split into three identical entities and sent to the loading, fueling, and maintenance activities. These entities will be matched up again prior to departure. If there is not enough ramp space, the aircraft leaves the system. Before being terminated, the entity is routed to a COLCT node by aircraft type. These COLCT nodes keep track of how many aircraft, by type, balk from the airfield.

No time is used in the arrival process. This is because the landing, taxiing, and takeoff of an aircraft is not modeled. The purpose of the model is to examine aspects of air-

field operation that limit its capacity. An assumption is made that the runway will not be a limiting factor for an airfield until arrivals exceed one every four minutes. A single runway airfield can handle an arrival and departure every four minutes, even in poor weather. The scenarios that will be examined in this study have aircraft arriving no faster than one every 13 minutes.

The values used for the pallet capacity of the aircraft were obtained from Air Force (Ref 11). The number of fuel trucks required was obtained in the following manner. It is assumed that each truck carries a full load of approximately 30,000 pounds of fuel and that each aircraft will load half of its fuel capacity before departing. The fuel capacity of the C-130, C-141, and C-5 is about 60,000, 120,000, and 250,000 pounds respectively. These figures were obtained from Air Force. These yield the requirements of one fuel truck for the C-130, two for the C-141, and four for the C-5. The values for the ramp required were obtained in the following way. On Green Ramp at Pope AFB, NC, there are parking spots for either 13 C-130s, 10 C-141s, or 7 C-5s. If the ramp requirement for a C-130 was 10 units, then a C-141 would need 13 units and a C-5 about 18. The ramp resource can be calculated by determining the number of any type aircraft that can park on the airfield and multiplying that number by the ramp resource each aircraft requires. For example, 100 C-130s can park at Wright-Patterson AFB; therefore, the ramp resource

would be 1000.

Loading

The loading activity is the most complicated of the three. An aircraft is directed to a GOON node as shown in Fig. 2.3. The entity then goes to an ASSIGN node where global variable XX(15) is updated. XX(15) stores the amount of ramp in use. From the ASSIGN node, the entity is directed to one of two processes. These are the pallet loading process and the rolling stock l..ding process.

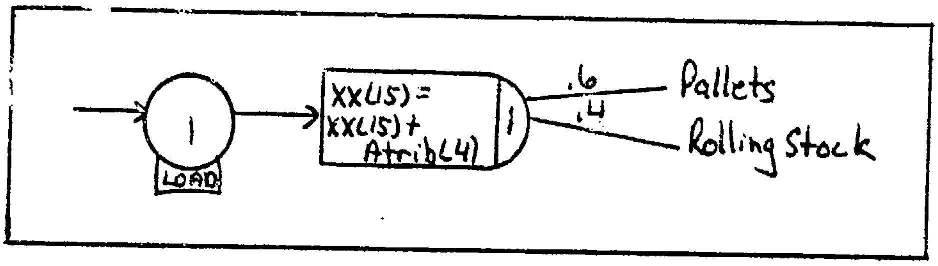

Fig. 2.3 SLAM Network - Aircraft Load Decision

An "infinite" cargo yard assumption is made. There is always cargo to be loaded or the aircraft would not have been sent to the airfield. In addition, no mixed loads or less than full loads are permitted. The aircraft entity will be loaded to its capacity once it is routed to either type of loading activity. In reality, mixed loads are common. The assumption was made to simplify the structure of the model and should not make a significant impact.

Pallet Loading. This activity is shown in Fig. 2.4.

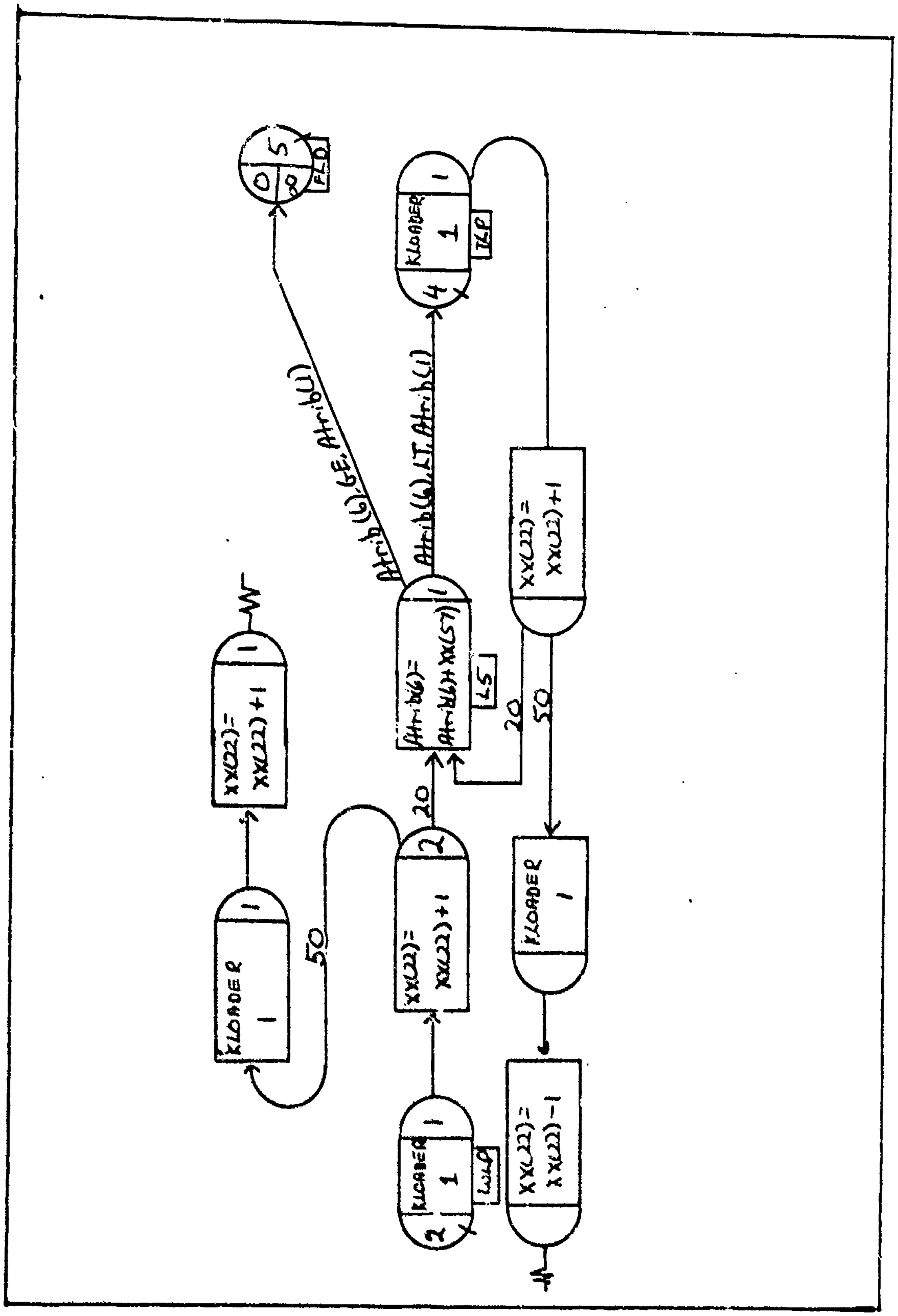

Fig. 2.4 SLAM Network - Pallet Loading

The aircraft is sent to an AWAIT node, WLP, where it awaits for a k-loader. Once assigned a k-loader, the entity departs for an ASSIGN node. The ASSIGN node adjusts the global variable XX(22). This variable represents the number of k-loaders in use. The k-loader spends 20 minutes loading the aircraft and 30 minutes returning to the cargo yard for another load. The k-loader then is occupied for 50 minutes before it is available to load again. After 50 minutes, the k-loader is freed and the number of k-loaders in use adjusted.

The entity is then routed to ASSIGN node L5. This node begins a process to determine if the aircraft is fully loaded. In the ASSIGN node, Atrib (6) is adjusted. Atrib (6) represents the number of pallet positions loaded. The attribute is incremented by the global variable XX(57) which can be set to either 3 or 5 to represent a 3 pallet or 5 pallet k-loader. From the ASSIGN node, the entity will take one of two activities. If it is fully loaded, it will go to node FLD. If not, it will go to node ILP for more loading. The node ILP is another AWAIT node like WLP except that entities waiting in ILP have priority for k-loaders over those in WLP. The process after WLP is exactly the same as that after ILP.

Rolling Stock. The network for loading rolling stock is shown in Fig. 2.5. The process is identical to that described for the pallet loading process with the following exceptions. The resource is used in load teams instead of k-loaders. A load team is two people. These people tie down the cargo with

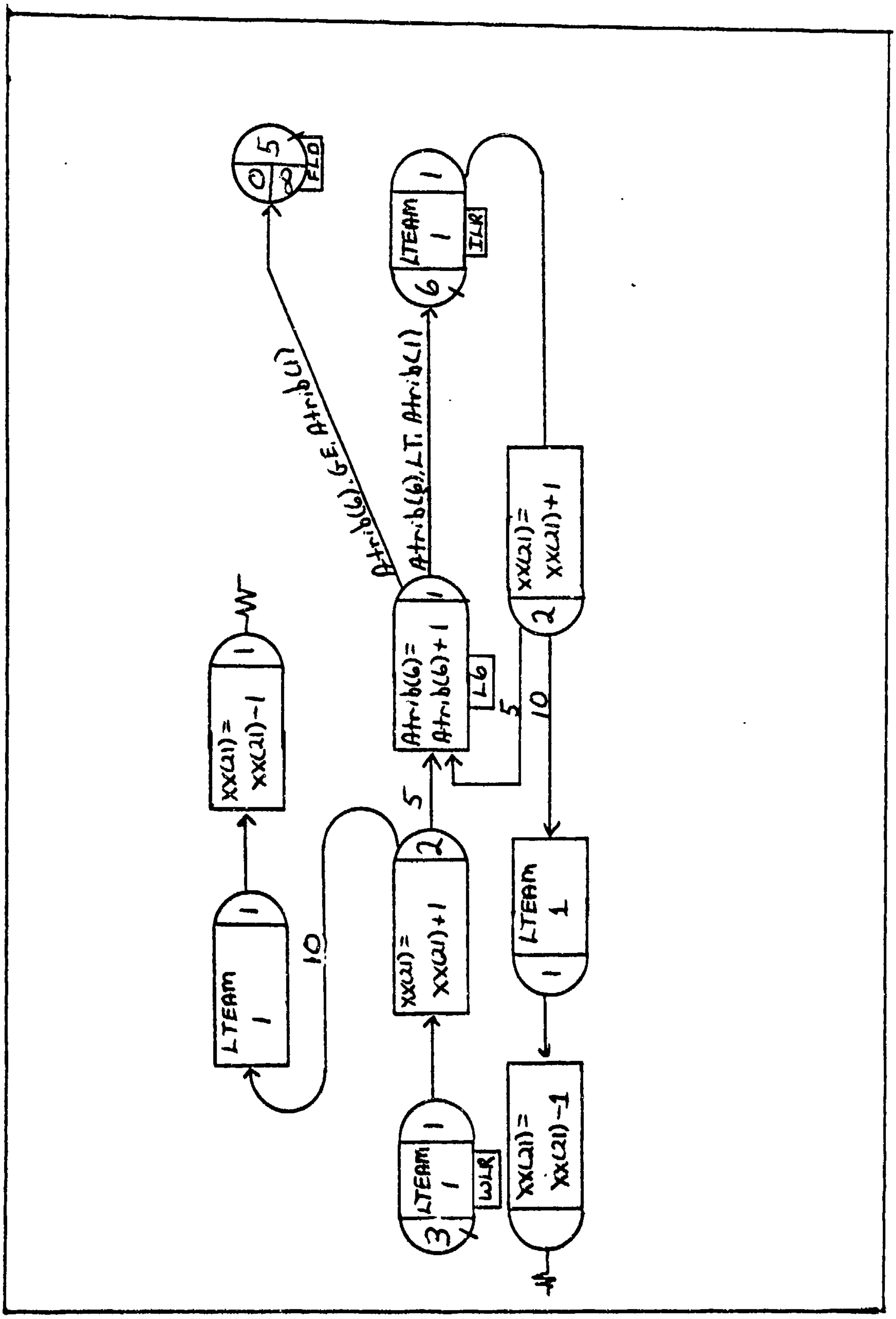

Fig. 2.5 SLAM Network - Loading Rolling Stock

chains. This activity takes five minutes. The ten minutes that the load team resource is used simulates the five minutes it takes to tie down the cargo and five minutes to either go get some more chains to tie down more cargo or go to another airplane. The global variable XX(21) is used to track the number of load teams in use.

Maintenance

Fig. 2.6 shows the SLAM network used to simulate the maintenance process. The aircraft entity is first routed to a node by type of aircraft. A C-130 would be sent to AC1 since it has five pallets. Then it is determined if the aircraft requires maintenance. If the value of Atrib (3) is less than the value in global variable XX(58), XX(59) or XX(60) as appropriate, the aircraft entity is routed to WMNX to wait for maintenance. If the value in Atrib (3) is greater than the global variable, the aircraft does not need maintenance and is routed to FMNX.

Aircraft requiring maintenance are placed in the AWAIT node WMNX. When a maintenance team is available, the team is allocated to the aircraft and repairs begin. A maintenance team consists of people with all the skills needed to repair an aircraft. The team would have an engine/prop specialist, a pneumatic/hydraulic specialist, and an avionics specialist. It is assumed there is an infinite supply capability and that all the tools necessary to make repairs are available.

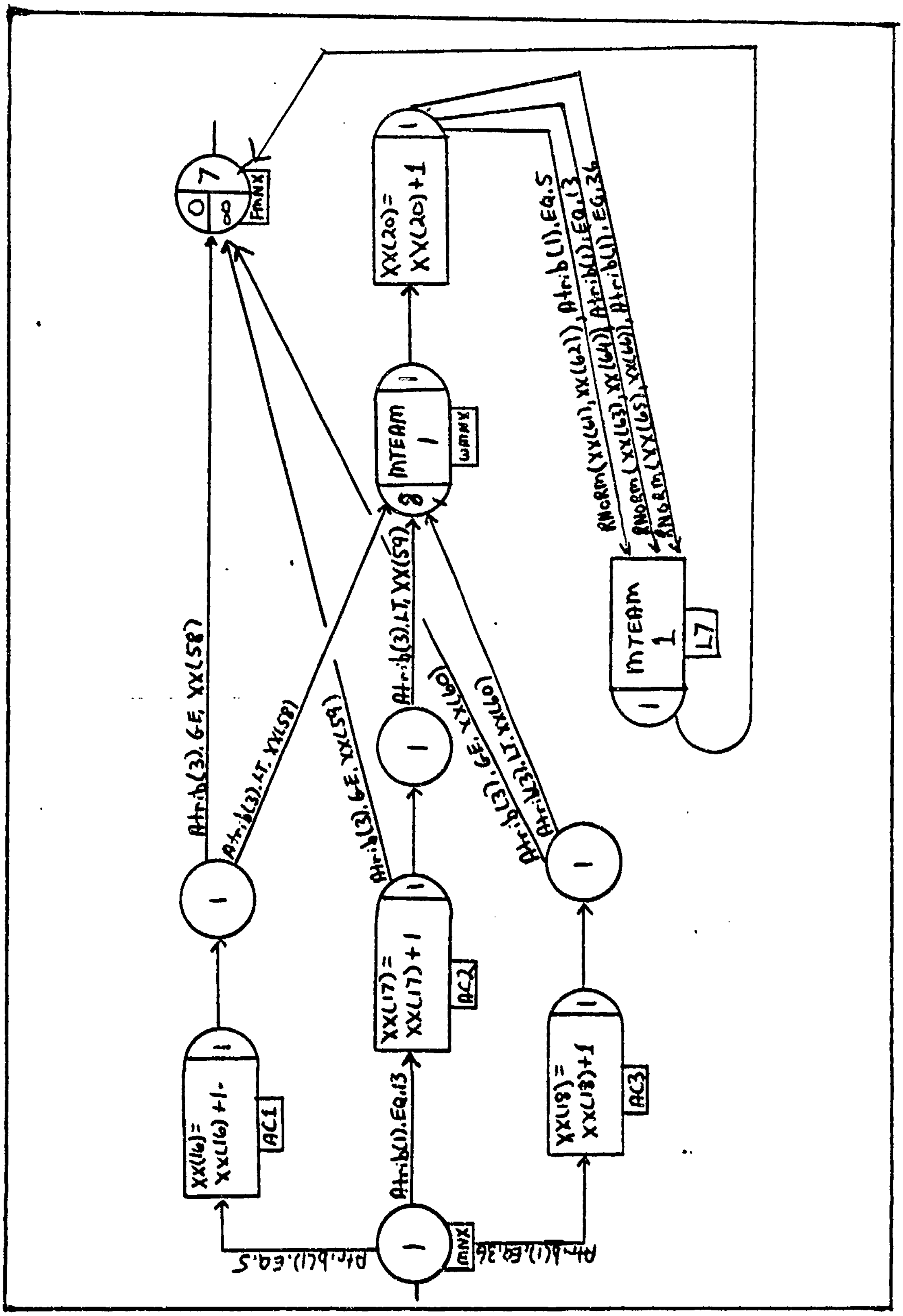

Fig. 2.6 SLAM Network - Maintenance

After leaving the AWAIT node with its maintenance team, the aircraft entity passes through an ASSIGN node that increments the global variable XX(20). This global variable represents the number of maintenance teams in use and is set using the global variables XX(61) to XX(66). After completing the repair activity, the aircraft is routed to node L7. At L7, the maintenance team is freed. At the ASSIGN node, the global variable XX(20) is adjusted to show the number of maintenance teams in use. Finally, the repaired aircraft is placed is QUEUE node FMNX.

Fueling

The network for the fueling process is shown in Fig. 2.7. The resource used in this process is a fuel truck. The process is identical to both of the loading activities. The aircraft waits initially in an AWAIT node to be assigned a gas truck. After 20 minutes, the gas truck completes off-loading its fuel and returns to the fuel storage area for another load of fuel. The aircraft entity in the meantime is sent to ASSIGN L8, where it is determined if the aircraft has finished fueling. If it has finished, it goes to QUEUE node FLG; if not, it goes to AWAIT node ILG; if not, it goes to AWAIT node ILG where it has priority for fuel trucks over those in AWAIT node GAS. The global variable XX(1() is used to track the number of fuel trucks in use.

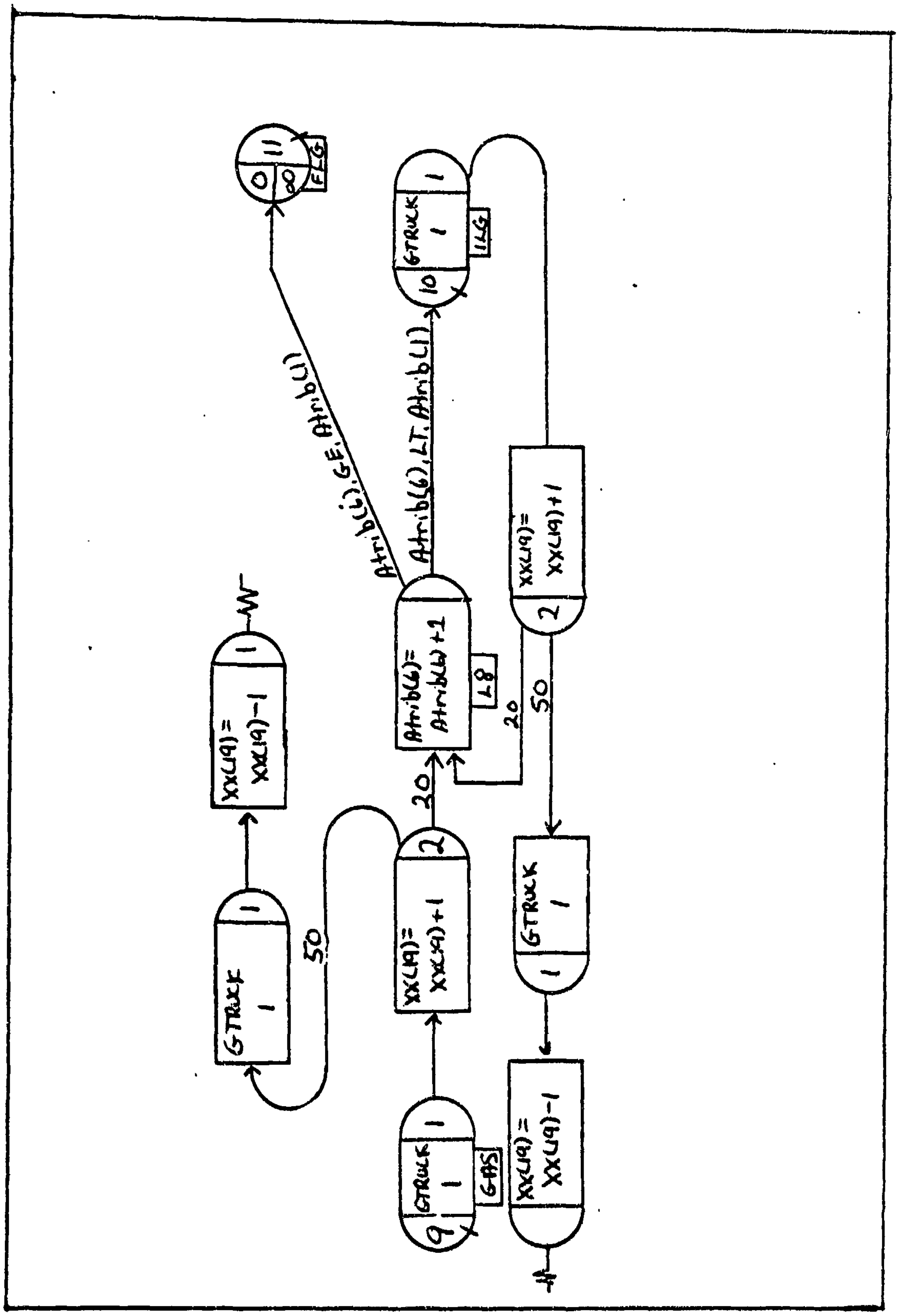

Fig. 2.7 SLAM Network - Fueling

Departure

The departure process is modeled by the network shown in Fig. 2.8. Entities wait in the QUEUE nodes FLG, FLD, and FMNX after finishing fueling, loading, and maintenance. Every airplane entering the system was spit into three entities to go through the three activities. These three entities with the same mark time are matched at MAT and sent to ACCUMULATE node TOF where they are made into one entity. This entity is sent through an ASSIGN node that increments the global variable XX(15). This variable stores the amount of ramp space in use. From the ASSIGN node, the entity is routed through a FREE node to release the ramp resource it used and then sorted by aircraft type through a statistics-gathering network. In the ASSIGN nodes, the global variables XX(16), XX(17), and XX(18) are updated to show the number of each type of aircraft on the ground. The COLCT nodes determine the average ground service time for each type of aircraft. The entities are then sent to ASSIGN node L9 for some final bookkeeping, followed by a COLCT node and termination. The ASSIGN node updates total pallets airborne, XX(27), balked pallets XX(10) and XX(12), and effective pallets XX(14). The effective pallets are the total pallets airborne with a penalty applied for each pallet that balks. For every pallet that balks the airfield, a pallet is subtracted from the total number of pallets that have departed the airfield.

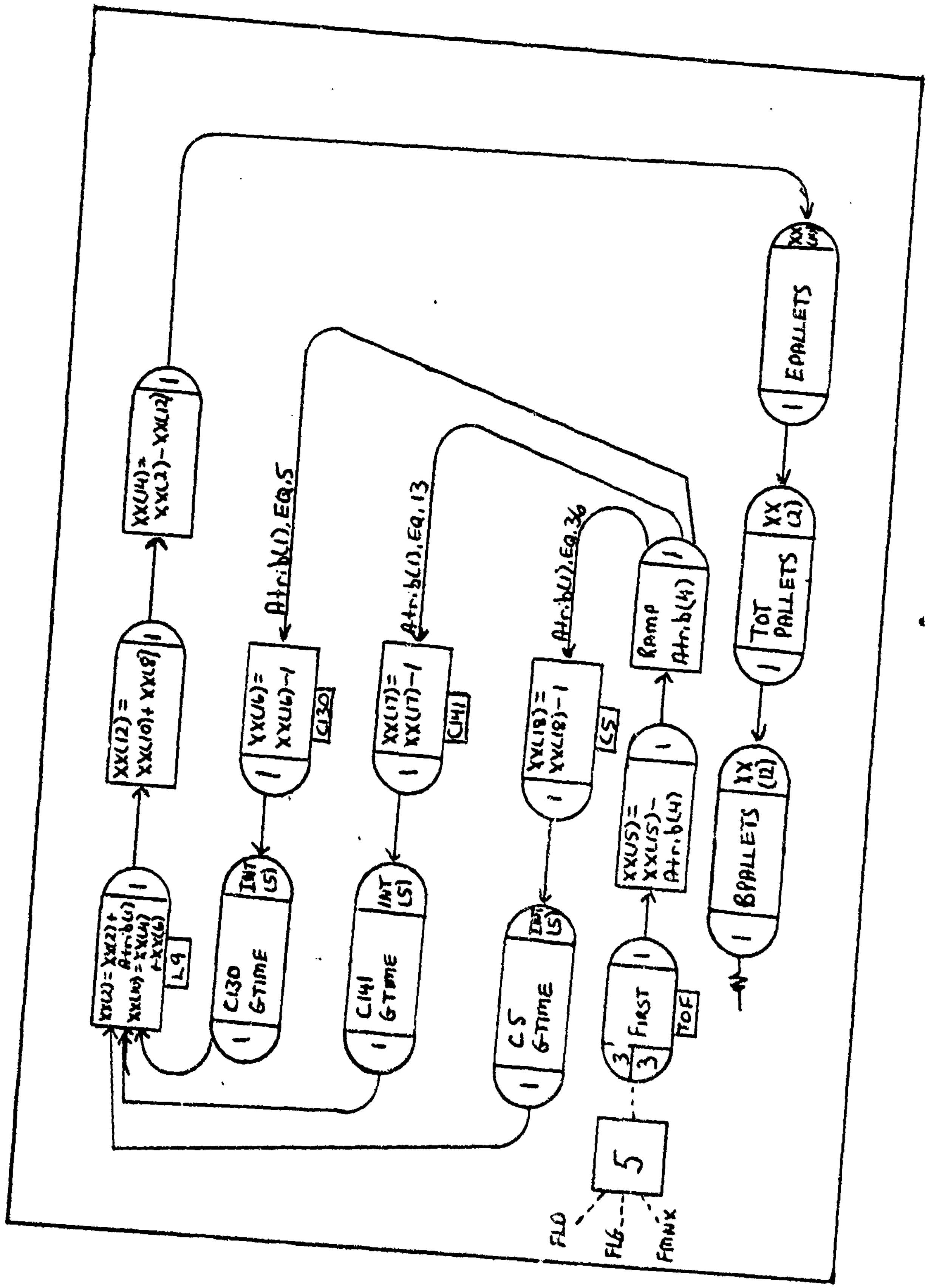

Fig. 2.8 SLAM Network - Departure

Verification and Validation

This portion of the model building process was accomplished in several steps. First, the five segments, that were described in the previous section, were coded separately. These segments were run over a range of scenarios. The output was checked to insure that the segment performed as expected. If any bugs were found, the code was corrected and the process repeated.

After all of the segments had been checked, the model was built by combining the segments one at a time. After adding each segment, more computer runs were made to check the interconnection of the segments. Finally, after all the segments were combined, the output of the model as a whole was checked to see that it gave reasonable results.

Conclusion

This chapter has explained the operations of an airfield during airlift operations and explained the model used to simulate that operation. In general, the airfield is described by the resources available on it, the cargo mix at the base, the time it takes for the resources to perform their function, and the rules used to govern the assignment of the resources. The values of resources are set on resource cards and are:

1) Ramp
2) K-Loaders
3) Load Teams

4) Maintenance Teams

5) Gas Trucks

The cargo mix used in the model is determined by assigning values to the probability of taking each activity in the ASSIGN node after LOAD.

The times required for the resources to perform their functions are set by global variables. Finally, the rules to govern the assignment of these resources are set, using a Priority card for the appropriate files.

The next chapter will discuss the output of the model and the use of the model in an attempt to find a "best" mix of aircraft input rates through an airfield to maximize the airlift through the airfield. The discussion will include the model setup, experimental design, and analysis of results.

III. Experimentation and Analysis

Introduction

The previous chapter described an airfield during airlift operations and a computer model that was designed to simulate it. This chapter will describe the use of the model in examining the flow of airlift aircraft through an airfield. The model setup section will state the airfield chosen for examination and the model parameters chosen to describe the airfield. In the experimental design section, the method used in identifying a "best" aircraft input strategy will be outlined. The final section will state the results obtained from the experiment.

Model Setup

The airfield chosen for examination was Wright-Patterson AFB, Ohio. Under current warplans, Wright-Patterson will be an onload point for units from several states on their way overseas (Ref 10). Cargo will arrive by air, rail, and road and then be marshalled for final transport overseas.

Before the model could be run, a number of inputs had to be provided to describe the airfield and its operation. These inputs are listed below:

1) Aircraft Input rate by type
2) Ramp Resource
3) Gas Truck Resource
4) Load Teams Resource

5) Maintenance Teams Resource

6) K-Loader Resource

7) Cargo Mix

8) Aircraft Failure Rate

9) Aircraft Maintenance Time

A range of input rates for aircraft was examined. The lowest input rate examined for the C-130 and C-141 was 1 aircraft every 2 hours, while the highest was 1 aircraft every 30 minutes. For the C-5 aircraft, the lowest input rate was 1 aircraft every 8 hours, while the highest input rate was 1 aircraft every 2 hours. The reason slower input rates were chosen for the C-5 was because there are fewer C-5s in the inventory by a factor of about four (Ref 11). A C-5 input rate that is four times slower, then, represents the same relative effort for that fleet. Table 3.1 shows the arrival rates by aircraft that were examined.

C-130	C-141	C-5
30	30	120
60	60	240
90	90	360
120	120	480

Table 3.1 Mean Aircraft Interarrival Times (in Minutes)

The levels of the other resources and the source from which the information came are shown in Table 3.2.

Parameter	Level	Source
Gas Trucks	6	Military Airlift Command (Ref 9)
Ramp	1000	Military Airlift Command
K-Loaders	4	Military Airlift Command
Maintenance Teams	4	Researcher
Load Teams	26	Transportation Office (Ref 5)
Aircraft Failure Rate	.13	Researcher
Maintenance Time:		
C-130 (mean)	4 hr	Researcher
C-141 (mean)	5 hr	Researcher
C-5 (mean)	9 hr	Researcher

Table 3.2 Parameter Specifications

The information from the Military Airlift Command is data its Operations Research Office (XPSR) uses for Wright-Patterson AFB in unclassified runs of its M-14 model. The Transportation Office of Headquarters Air Force Logistics Command at Wright-Patterson AFB, Ohio provided the information on the number of load teams that would be available (Ref 5). The parameters required for the maintenance segment of the model were set at levels chosen by the researcher.

All the possible combinations of input rates for the three types of aircraft were then run through the model with the airfield parameters set as indicated in Table 3.2. Since there were four levels for each of the three types of aircraft,

this meant 64 computer runs were made to examine all the strategies. A strategy is a mix of aircraft input rates. For example, one C-130 every 90 minutes, one C-141 every 30 minutes, and one C-5 every 240 minutes will be referred to as strategy (90, 30, 240).

On the first few runs of the model, twenty replications were made for each strategy. The purpose of these runs was to measure the variance in the response variable EPALLETS. Table 3.3 shows the variance that was obtained for two strategies after a specified number of runs.

	Number of Runs			
Strategy	5	10	15	20
(30, 90, 180)	130	202	201	247
(180, 180, 1440)	132	108	93	87

Table 3.3 Variance by Strategy by Number of Runs

There was no assurance that variance would be reduced by increasing the number of runs. Therefore, all strategies were run using 5 replications. The model was run on both the CDC Cyber and VAX 11/780 computers. The CDC Cyber required, on average, 100 seconds of computer time to run five replications of each strategy. The VAX 11/780, on the other hand, required 300 seconds of computer time to complete the five replications.

The output of these runs consisted of the standard SLAM Summary and seven plots. The following information was obtained from the SLAM Summary:

1) Number of balks by aircraft type

2) Mean, minimum, and maximum groundtime by aircraft type

3) Total pallets airborne

4) Balked pallets

5) Effective pallets

6) Average resource usage

7) Average resource availability

The plots provided hourly reports on the following information:

1) Ramp in use

2) Gas trucks in use

3) K-loaders in use

4) Maintenance teams in use

5) Load teams in use

6) Number of aircraft on the ground by type

7) Total, balked, and effective pallets to date

An example of model output is shown in the Appendix.

Experimental Design

After making the 64 runs, the attempt to identify a "best" policy among the 64 began. The 64 strategies with five replications comprised 64 cells of 5 observations each. First, strategies were eliminated by a screening test. Any strategy that resulted in aircraft balking from the airfield for lack of ramp space was eliminated from further consideration. A strategy that results in aircraft flying to an air-

field where they cannot land is clearly wasteful. The remaining strategies were then ordered by the mean of effective pallets over the five replications. ANOVA was then run on the five replications of the top twenty strategies. Finally, the best group of strategies was identified using the Duncan Procedure for range testing.

Results

The ANOVA was run using SPSS on the CDC Cyber computer. The null hypothesis was that the twenty groups (strategies) all had the same mean. This hypothesis was rejected with an F Prob of .000. A copy of the ANOVA table is included in the Appendix.

ANOVA makes the assumption that the data is independent and normally distributed with equal variance. Additional tests were made to insure the assumptions held for this data set. The data was independent since it was generated by separate computer runs with the model reinitialized after each run. A K-S test was run on the first five strategies to test the normality assumption. The test failed to reject the hypothesis that the groups were normally distributed. It was assumed that the remaining 15 strategies would also pass the K-S test. The SPSS run included a Bartlett Box F test to check for equal variance. The test failed to reject the hypothesis that the variance was equal across all the groups. Therefore, the assumptions of ANOVA were met.

Since the ANOVA indicated there was a difference among the means of the strategies, a Duncan Range Test was used to determine which groups were statistically different from the others. The computer printout of the test is also shown in the Appendix. The test indicated there was no statistical difference in the first five strategies. The top ten strategies are shown in Table 3.4.

Strategy			Effective Pallets
90	90	120	2864
60	120	120	2782
120	90	120	2754
30	90	240	2751
60	60	240	2712
90	120	120	2667
120	120	120	2638
90	60	240	2627
30	120	240	2608
120	60	240	2554

Table 3.4 Top Ten Strategies for Effective Pallets

Conclusion

Since there is no statistical difference in the output of the first five strategies, a decision maker could choose from among these strategies based on other considerations. The considerations could be the availability of aircraft or

the desire to minimize ground time for the aircraft. The final chapter will summarize the results of the research and suggest ways to further develop the model.

IV. Summary and Recommendations

Summary

One objective of the research was to develop a user friendly airfield model specifically designed for airlift operations. The primary way the developed model meets the user friendly requirement is its size. The model is not so large that it would intimidate potential users into not examining it. The network formulation of the model also contributes to its user friendly aspect. The network symbols can help potential users understand what the code is accomplishing.

The small size of the model also helps shorten model setup time. In order to examine different aircraft input rates, a user only needs to change the values of global variables. If, instead, he wishes to change the resources available on the airfield, only the resource cards have to be changed. As the documented program in the Appendix shows, these cards are consolidated in different parts of the program. During the research, changes to aircraft input rates were made in three minutes by the researcher. Other types of changes could also be made in a matter of minutes. This is in contrast to the days and months it takes to set up other models examined in this research. The size advantage makes the model useful to lower level managers who want quick investigation of a proposed airlift operation. The

managers could be exercise planners or base mobility planners.

A second objective of the model was to provide information on the important elements of the airfield operation. The standard SLAM Summary provides information on aircraft ground time, airfield resource utilization, and airfield output. The graphs provided give more information on these quantities as a function of time.

Recommendations

Simulation model building is an iterative process, and any model can be made to more accurately model the system it represents as more knowledge of the system becomes available (Ref 8:11). The following paragraphs will suggest ways to improve the model.

No model can be stronger than its weakest link. Conceptually, the maintenance segment of this model is its weakest link. The maintenance team concept used in the model is not how a maintenance resource is actually managed. Only the specific skilled person required for a job is dispatched to repair an aircraft, not an entire team of people made up of every skill that could possibly be needed. The maintenance team concept used in the model is essentially a measure of how many aircraft the model user thinks could be under repair at one time. Additionally, the parameters used for the percentage of aircraft that break and the amount of time to repair them must be estimated by the model user. The

validity of the model would be enhanced, if the maintenance resource could be more realistically defined and historical data could be investigated to determine break rates and mean repair times for aircraft.

Next, the output of the model could be streamlined. There are some items in the standard SLAM Summary that are meaningless such as mean or standard deviation of EPALLETS. A new subroutine could be written to output only the elements of the SLAM Summary that are useful. In addition, new graphs could be made to present such information as number of aircraft by type waiting in each of the QUEUE or AWAIT nodes.

Although there are improvements that could be made to the model, care should be taken in making these changes. The changes should not make the model too complicated to understand or demand too much in input from the user. If the model becomes so complex that it itimidates potential users, the worth of the model decreases regardless of its accuracy in modeling the system.

Appendix A

Model and Sample Output

```
gen,johnson,airfield,12/19/1983,5;
limits,11,6,700;
network;
;*****************************************************************
;   THE RESOURCES OF THE AIRFIELD MUST BE SET. THESE ARE:
;          1. RAMP
;          2. KLOADERS
;          3. LOAD TEAMS
;          4. MAINTENANCE TEAMS
;          5. GAS TRUCKS
;     THEY ARE DETERMINED IN THE FOLLOWING WAY:
;          1. RAMP= THE NUMBER OF C-130S THAT CAN PARK ON THE
;             AIRFIELD TIMES TEN.
;          2. KLOADERS= THE NUMBER OF KLOADERS AVAILABLE
;          3. LOAD TEAMS= THE NUMBER OF TWO MAN TEAMS AVAILABLE
;             FOR SECURING ROLLING STOCK ON THE AIRCRAFT
;          4. MTEAMS= THE NUMBER OF AIRCRAFT THAT CAN BE UNDER
;             REPAIR AT THE SAME TIME UNDER THE WORST CONDITIONS
;             WITH THE MAINTENANCE PEOPLE AVAILABLE
;          5. GTRUCKS= THE NUMBER OF GAS TRUCKS AVAILABLE.
;*****************************************************************
      resource/ramp(1000),1;
      resource/Kloader(4),4,2;
      resource/lteam(26),6,3;
      resource/mteam(4),8;
      resource/gtruck(6),10,9;
;*****************************************************************
;   THIS SECTION PUTS AIRCRAFT INTO THE SYSTEM, AND TAGS THEM
;   WITH THEIR ATTRIBUTES.  IF NO PARKING SPACE IS AVAILABLE THE
;   AIRCRAFT ARE BALKED FROM THE AIRFIELD. THE FOLLOWING GLOBAL
;   VARIABLES MUST BE SET BY INTLC CARDS AT THE END OF THE
;   PROGRAM:
;       XX(50)=C-130 INTERARRIVAL TIME IN MINUTES
;       XX(51)=C-141 INTERARRIVAL TIME IN MINUTES
;       XX(52)=C-5   INTERARRIVAL TIME IN MINUTES
;   THE FOLLOWING GLOBAL VARIABLE IS USED BUT DOES NOT HAVE TO
;   TO BE SET BY THE USER:
;       XX(1)= RAMP RESOURCE AVAILABLE
;       XX(3)= C-130 BALKS
;       XX(4)= C-130 PALLETS BALKED
;       XX(5)= C-141 BALKS
;       XX(6)= C-141 PALLETS BALKED
;       XX(7)= C-5 BALKS
;       XX(8)= C-5 PALLETS BALKED
;   THE ATTRIBUTES OF THE AIRCRAFT ENTITIES ARE:
;       ATRIB(1)= PALLET CAPACITY OF THE AIRCRAFT
;       ATRIB(2)= GAS TRUCKS REQUIRED TO REFUEL
;       ATRIB(3)= AIRCRAFT MAINTENANCE STATUS
;       ATRIB(4)= RAMP RESOURCE REQUIRED
;       ATRIB(5)= MARK TIME
;*****************************************************************
      create,expon(xx(50),1),1,5;
      assign,atrib(1)=5,atrib(2)=1,atrib(4)=10;
```

```
    act,,,11;
    create,expon(xx(51),2),2,5;
    assign,atrib(1)=13,atrib(2)=2,atrib(4)=13;
    act,,,11;
    create,expon(xx(52),3),3,5;
    assign,atrib(1)=36,atrib(2)=4,atrib(4)=18;
    act,,,11;
 11 assign,atrib(3)=unfrm(0,1,4),xx(1)=nnrsc(ramp);
    goon,1;
    act,,atrib(4).gt.xx(1),ofl;
    act,,atrib(4).le.xx(1);
    await(1),ramp/atrib(4);
    act,,,load;
    act,,,mnx;
    act,,,gas;
ofl goon,3;
    act,,atrib(1).eq.5,12;
    act,,atrib(1).eq.13,13;
    act,,atrib(1).eq.32,14;
12  assign,xx(3)=xx(3)+1,xx(4)=xx(4)+5;
    colct,xx(3),c130balks;
    term;
13  assign,xx(5)=xx(5)+1,xx(6)=xx(6)+13;
    colct,xx(5),c141balks;
    term;
 14 assign,xx(7)=xx(7)+1,xx(8)=xx(8)+32;
    colct,xx(7),c5balks;
    term;
;*****************************************************************
;     THIS SECTION SIMULATES THE LOADING OF THE AIRCRAFT.
;     THERE ARE TWO TYPES OF LOADS: PALLETS (WLP) AND ROLLING
;     STOCK (WLR).  THE CARGO IS DETERMINED BY THE PROBABILITIES
;     OF REACHING THESE ACTIVITIES.  IN THIS CASE, 60% PALLETS
;     ARE LOADED, AND 40% ROLLING.  THE CARGO MIX CAN BE CHANGED
;     BY CHANGING THE PROBABILITIES.  GLOBAL VARIABLE XX(15)
;     STORES THE RAMP SPACE IN USE.
;*****************************************************************
load goon,1;
    assign,xx(15)=xx(15)+atrib(4);
    act,,.6,wlp;
    act,,.4,wlr;
;*****************************************************************
;     THIS SECTION SIMULATES THE PALLET LOADING PROCESS.
;     THE GLOBAL VARIABLE XX(57) MUST BE SET ON AN INTLC CARD.
;         XX(57)= NUMBER OF PALLETS A KLOADER CAN CARRY (3 OR 5)
;         ATRIB(6)= NUMBER OF PALLETS LOADED ON THE AIRCRAFT
;     THE GLOBAL VARIABLE XX(22) TRACKS THE NUMBER OF KLOADERS
;     IN USE BUT DOES NOT HAVE TO BE SET BY THE USER.
;*****************************************************************
 wlp await(2),Kloader/1;
    assign,xx(22)=xx(22)+1;
    act,20,,15;

    act,50;
    free,Kloader/1;
    assign,xx(22)=xx(22)-1;
```

```
     term;
 15  assign,atrib(6)=atrib(6)+xx(57),1;
     act,,atrib(6).lt.atrib(1),ilp;
     act,,atrib(6).ge.atrib(1),fld;
 ilp await(4),Kloader/1;
     assign,xx(22)=xx(22)+1;
     act,20,,15;
     act,50;
     free,Kloader/1;
     assign,xx(22)=xx(22)-1;
     term;
;*****************************************************************
;    THE FOLLOWING SECTION SIMULATES THE LOADING OF ROLLING
;    STOCK. GLOBAL VARIABLE XX(21) TRACKS THE NUMBER OF LOAD
;    TEAMS IN USE.
;*****************************************************************

 wlr await(3),lteam/1;
     assign,xx(21)=xx(21)+1;
     act,5,,16;
     act,10;
     free,lteam/1;
     assign,xx(21)=xx(21)-1;
     term;
 16  assign,atrib(6)=atrib(6)+1,1;
     act,,atrib(6).lt.atrib(1),ilr;
     act,,atrib(6).ge.atrib(1),fld;
 ilr await(6),lteam/1;
     assign,xx(21)=xx(21)+1;
     act,5,,16;
     act,10;
     free,lteam/1;
     assign,xx(21)=xx(21)-1;
     term;
 fld queue(5),,,,mnt;
;*****************************************************************
;    THIS SECTION SIMULATES THE MAINTENANCE OF AIRCRAFT.
;    FIRST, A TEST IS MADE TO SEE IF THE AIRCRAFT IS BROKEN.
;    IF IT IS, IT WAITS TO BE REPAIRED, IF NOT , IT GOES
;    TO QUEUE NODE FMNX TO WAIT FOR DEPARTURE. THE FOLLOWING
;    GLOBAL VARIABLES MUST BE SET BY INTLC CARDS AT THE END
;    OF THE PROGRAM:
;      XX(58)=PROBABILITY THAT A C-130 WILL BE BROKEN
;      XX(59)=PROBABILITY THAT A C-141 WILL BE BROKEN
;      XX(60)=PROBABILITY THAT A C-5 WILL BE BROKEN
;      XX(61)=MEAN TIME TO REPAIR A C-130 IN MINUTES
;      XX(62)=STANDARD DEVIATION FOR C-130 IN MINUTES
;      XX(63)=MEAN TIME TO REPAIR A C-141 IN MINUTES
;      XX(64)=STANDARD DEVIATION FOR C-141 IN MINUTES
;      XX(65)=MEAN TIME TO REPAIR A C-5 IN MINUTES
;      XX(66)=STANDARD DEVIATION FOR A C-5 IN MINUTES
;    THE FOLLOWING GLOBAL VARIABLES ARE USED BUT DO NOT
;    HAVE BE SET BY THE USER:
;      XX(20)=NUMBER OF MAINTENANCE TEAMS IN USE
;      XX(16)=NUMBER OF C-130S ON THE AIRFIELD
;      XX(17)=NUMBER OF C-141S ON THE AIRFIELD
```

```
;        XX(18)=NUMBER OF C-5S ON THE AIRFIELD
;*********************************************************
  mnx goon,1;
      act,,atrib(1).eq.5,ac1;
      act,,atrib(1).eq.13,ac2;
      act,,atrib(1).eq.36,ac3;
  ac1 assign,xx(16)=xx(16)+1;
      goon,1;
      act,,atrib(3).gt.xx(58),fmnx;
      act,,atrib(3).le.xx(58),wmnx;
  ac2 assign,xx(17)=xx(17)+1;
      goon,1;
      act,,atrib(3).gt.xx(59),fmnx;
      act,,atrib(3).le.xx(59),wmnx;
  ac3 assign,xx(18)=xx(18)+1;
      goon,1;
      act,,atrib(3).gt.xx(60),fmnx;
      act,,atrib(3).le.xx(60),wmnx;
 wmnx await(8),mteam/1,1;
      assign,xx(20)=xx(20)+1,1;
      act,rnorm(xx(61),xx(62),5),atrib(1).eq.5,17;
      act,rnorm(xx(63),xx(64),6),atrib(1).eq.13,17;
      act,rnorm(xx(65),xx(66),7),atrib(1).eq.36,17;
  17  free,mteam/1;
      assign,xx(20)=xx(20)-1;
      goon,1;
 fmnx queue(7),,,,mat;
;*********************************************************
;    THIS SECTION SIMULATES THE FUELING OF AIRCRAFT.
;    THE GLOBAL VARIABLE XX(19) TRACKS THE NUMBER OF
;    GAS TRUCKS IN USE.  ATRIB(6)= THE NUMBER OF
;    TRUCK LOADS OF FUEL LOADED ON THE AIRCRAFT.
;*********************************************************
  gas await(9),gtruck/1;
      assign,xx(19)=xx(19)+1;
      act,20,,18;
      act,50;
      free,gtruck/1;
      assign,xx(19)=xx(19)-1;
      term;
   18 assign,atrib(6)=atrib(6)+1,1;
      act,,atrib(6).lt.atrib(2),ilg;
      act,,atrib(6).ge.atrib(2),flg;
  ilg await(10),gtruck/1;
      assign,xx(19)=xx(19)+1;
      act,20,,18;
      act,50;
      free,gtruck/1;
      assign,xx(19)=xx(19)-1;
      term;
  flg queue(11),,,,mat;
;*********************************************************
;      THIS SECTION MATCHES FULLY SERVICED AIRCRAFT AND
;      MAKES THEM DEPART THE AIRFIELD.  THE FOLLOWING
;      GLOBAL VARIABLES ARE USED BUT DO NOT HAVE TO BE SET
;      BY THE USER:
```

```
;        XX(2)= TOTAL PALLETS DEPARTING THE AIRFIELD TO DATE
;        XX(10)=TOTAL C-130 AND C-141 PALLETS THAT BALK
;        XX(12)=TOTAL PALLETS THAT BALK
;        XX(14)=TOTAL PALLETS-BALKED PALLETS
;****************************************************
  mat match,5,flg/tof,fmnx/tof,fld/tof;
   tof accumulate,3,3,first,1;
       assign,xx(15)=xx(15)-atrib(4);
       free,ramp/atrib(4),1;
       act,,atrib(1).eq.5,c130;
       act,,atrib(1).eq.13,c141;
       act,,atrib(1).eq.36.c5;
 c130 assign,xx(16)=xx(16)-1;
       colct,intvl(5),c130gtime;
       act,,,19;
 c141 assign,xx(17)=xx(17)-1;
       colct,intvl(5),c141gtime;
       act,,,19;
    c5 assign,xx(18)=xx(18)-1;
       colct,intvl(5),c5gtime;
       act,,,19;
    19 assign,xx(2)=xx(2)+atrib(1);
       assign,xx(10)=xx(4)+xx(6);
       assign,xx(12)=xx(10)+xx(8);
       assign,xx(14)=xx(2)-xx(12);
       colct,xx(14),epallets;
       term;
       endnetwork;
;********************************************************
;     THIS SECTION OF THE PROGRAM SETS THE LENGTH OF THE
;     SIMULATION (7200 MINUTES=5 DAYS).  THE PRIORITY FOR
;     THE FILES ARE SET, AND THE REQUIRED GLOBAL VARIABLES
;     ARE SET BY CALLS TO INTLC.  THE RECORD AND VAR CARDS
;     PRODUCE THE GRAPH
;********************************************************
init,0,7200;
priority/2,hvf(1)/3,hvf(1)/4,lvf(5)/6,lvf(5)/8,hvf(1)/9,hvf(
intlc,xx(50)=120,xx(51)=120,xx(52)=480;
intlc,xx(57)=3;
intlc,xx(58)=.13,xx(59)=.13,xx(60)=.13;
intlc,xx(61)=240,xx(62)=24,xx(63)=300,xx(64)=30;
intlc,xx(65)=540,xx(66)=54;
record.tnow,time,1,,4:
var,xx(15),r,ramp,0,1000;
record,tnow,time,2,,4;
var,xx(19),t,gtruck,0,6;
record,tnow,time,3,,4;
var,xx(21),l,lteam,0,26;
record,tnow,time,4,,4;
var,xx(20),m.mteam,0,4;
record,tnow,time,8,,4;
var,xx(22),k,kloader,0,4;
record,tnow,time,9,,4;
var,xx(16),s,c130,0,100;
var,xx(17),m,c141,0,100:
var,xx(18),l,c5,0,100;
```

```
record,tnow,time,10,,4;
var,xx(2),a,pallab,0,4000;
var,xx(12),b,pallbl,0,4000;
var,xx(14),e,effpal,0,4000;
fin;
```

s l a m   s u m m a r y   r e p o r t

simulation project airfield   by johnson

date 12/19/1983   run number 1 of 1

current time .12ØØe+Ø3
statistical arrays cleared at time .ØØØØe+ØØ

statistics for variables based on observation

	mean value	standard deviation	coeff. of variation	minimum value	maximum value	number of observations
c13Øbalks	.17ØØe+Ø2	.967Øe+Ø1	.5688e+ØØ	.1ØØØe+Ø1	.33ØØe+Ø2	33
c141balks	.265Øe+Ø2	.1515e+Ø2	.5719e+ØØ	.1ØØØe+Ø1	.52ØØe+Ø2	52
c5balks	.35ØØe+Ø1	.1871e+Ø1	.5345e+ØØ	.1ØØØe+Ø1	.6ØØØe+Ø1	6
c13Øgtime	.1175e+Ø1	.1545e+Ø1	.1315e+Ø1	.4ØØØe+ØØ	.5779e+Ø1	41
c141gtime	.1613e+Ø2	.1687e+Ø2	.1Ø46e+Ø1	.1Ø4Øe+Ø1	.4633e+Ø2	125
c5gtime	.5965e+Ø1	.296Øe+Ø1	.4963e+ØØ	.256Øe+Ø1	.9836e+Ø1	33
epallets	.1248e+Ø4	.6267e+Ø3	.5Ø21e+ØØ	.5ØØØe+Ø1	.1942e+Ø4	199

file statistics

file number	associated node type	average length	standard deviation	maximum length	current length	average waiting time
1	await	.ØØØØ	.ØØØØ	1	Ø	.ØØØØ
2	await	56.7588	32.2986	9Ø	89	37.4234
3	await	.ØØØØ	.ØØØØ	1	Ø	.ØØØØ
4	await	1.Ø592	.7945	3	2	.2733
5	queue	.6898	1.Ø999	7	Ø	.3677
6	await	.ØØØØ	.ØØØØ	1	Ø	.ØØØØ
7	queue	59.9988	31.9Ø31	92	92	24.7418
8	await	.ØØØØ	.ØØØØ	1	Ø	.ØØØØ
9	await	.8178	2.Ø212	11	Ø	.3361
1Ø	await	.1534	.4357	3	Ø	.Ø751
11	queue	58.4446	32.6885	92	9Ø	24.2676
12	calendar	17.2282	5.733Ø	41	2Ø	.1215

resource statistics

resource number	resource label	current capacity	average utilization	standard deviation	maximum utilization	current utilization
1	ramp	1ØØØ	683.Ø416	345.1962	1ØØØ	998
2	kloader	4	3.8335	.7287	4	4
3	lteam	26	1.87Ø7	2.Ø692	13	2
4	mteam	4	.8913	.8Ø41	3	1
5	gtruck	6	3.696Ø	2.Ø784	6	5

resource number	resource label	current available	average available	minimum available	maximum available
1	ramp	2	316.9586	Ø	1ØØØ
2	kloader	Ø	.1665	Ø	4
3	lteam	24	24.1295	13	26
4	mteam	3	3.1ØØ7	1	4
5	gtruck	1	2.3Ø4Ø	Ø	6

1

table number 1
run number 1

```
time          ramp

   minimum    .ØØØØe+ØØ
   maximum    .998Øe+Ø3
1
```

plot number 1
run number 1

```
r=ramp                                                  scales of plot
Ø            .ØØØØe+ØØ                 .25ØØe+Ø3                .5ØØØe+Ø3                .75ØØe+Ø3
               Ø    5   1Ø   15   2Ø   25   3Ø   35   4Ø   45   5Ø   55   6Ø   65   7Ø   75   8Ø   85   9Ø
time

 .ØØØØe+ØØ  r                        +                        +                        +
 .4ØØØe+Ø1  +       r                +                        +                        +
 .8ØØØe+Ø1  +          r             +                        +                        +
 .12ØØe+Ø2  +           r            +                        +                        +
 .16ØØe+Ø2  +                 r      +                        +                        +
 .2ØØØe+Ø2  +                r       +                        +                        +
 .24ØØe+Ø2  +                        +    r                   +                        +
 .28ØØe+Ø2  +                        +       r                +                        +
 .32ØØe+Ø2  +                        +               r        +                        +
 .36ØØe+Ø2  +                        +                 r      +                        +
 .4ØØØe+Ø2  +                        +                       r+                        +
 .44ØØe+Ø2  +                        +                        +                 r      +
 .48ØØe+Ø2  +                        +                        +                 r      +
 .52ØØe+Ø2  +                        +                        +                     r  +
 .56ØØe+Ø2  +                        +                        +                        +    r
 .6ØØØe+Ø2  +                        +                        +                        +         r
 .64ØØe+Ø2  +                        +                        +                        +
 .68ØØe+Ø2  +                        +                        +                        +
```

Appendix B

SPSS Results

```
ASD COMPUTER CENTER
WRIGHT-PATTERSON AFB,OHIO

S P S S - - STATISTICAL PACKAGE FOR THE SOCIAL SCIENCES

VERSION 8.3 (NOS) -- MAY 04, 1982

376500 CM MAXIMUM FIELD LENGTH REQUEST



         RUN NAME          PALLETS
         VARIABLE LIST     STRATEGY,PALLETS
         INPUT MEDIUM      CARD
         N OF CASES        100
         INPUT FORMAT      FREEFIELD


         ONEWAY            PALLETS BY STRATEGY(1,20)/
                           RANGES=LSD/
                           RANGES=DUNCAN/
                           RANGES=SNK/
                           RANGES=SCHEFFE/
         STATISTICS        ALL
```

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQ.	MEAN SQ.	F RATIO	F PROB
BETWEEN GROUPS	19	2200181.440	115799.023	6.795	.000
WITHIN GROUPS	80	1363306.800	17041.335		
TOTAL	99	3563488.240			

GROUP	COUNT	MEAN	STAND. DEV.	STAND. ERROR	MIN.	MAX.	95 PERCENT CONF INT FOR MEAN
GRP 1	5	2863.60	96.12	42.99	2713.00	2945.00	2744.25 TO 2982.95
GRP 2	5	2781.60	104.69	46.82	2652.00	2942.00	2651.61 TO 2911.59
GRP 3	5	2754.20	211.16	94.43	2528.00	3064.00	2492.01 TO 3016.39
GRP 4	5	2750.80	158.42	70.85	2520.00	2885.00	2554.10 TO 2947.50
GRP 5	5	2712.20	103.21	46.16	2613.00	2865.00	2584.05 TO 2840.35
GRP 6	5	2666.80	116.09	51.92	2573.00	2856.00	2522.65 TO 2810.95
GRP 7	5	2637.80	201.49	90.11	2400.00	2911.00	2387.63 TO 2887.97
GRP 8	5	2627.00	129.26	57.81	2428.00	2760.00	2466.51 TO 2787.49
GRP 9	5	2628.00	125.47	56.11	2487.00	2814.00	2472.21 TO 2783.79
GRP 10	5	2554.40	99.01	44.28	2438.00	2711.00	2431.46 TO 2677.34
GRP 11	5	2547.20	132.44	59.23	2337.00	2701.00	2382.75 TO 2711.65
GRP 12	5	2543.20	111.98	50.08	2397.00	2644.00	2404.16 TO 2682.24
GRP 13	5	2487.80	72.06	32.22	2410.00	2562.00	2398.33 TO 2577.27
GRP 14	5	2477.40	124.01	55.46	2261.00	2560.00	2323.42 TO 2631.38
GRP 15	5	2457.20	77.87	34.82	2324.00	2526.00	2360.52 TO 2553.88
GRP 16	5	2441.20	103.96	46.49	2338.00	2605.00	2312.12 TO 2570.28
GRP 17	5	2439.00	127.37	56.96	2252.00	2585.00	2280.85 TO 2597.15
GRP 18	5	2360.60	192.41	86.05	2035.00	2491.00	2121.69 TO 2599.51
GRP 19	5	2357.20	134.69	60.24	2166.00	2502.00	2189.96 TO 2524.44
GRP 20	5	2348.00	71.05	31.77	2280.00	2466.00	2259.78 TO 2436.22
TOTAL	100	2571.76			2035.00	3064.00	

```
TESTS FOR HOMOGENEITY OF VARIANCES

   COCHRANS C = MAX.VARIANCE/SUM(VARIANCES) =    .1308, P =  .580 (APPROX.)
   BARTLETT-BOX F =                               .711, P =  .811
   MAXIMUM VARIANCE / MINIMUM VARIANCE =         8.833


DUNCAN PROCEDURE
RANGES FOR THE .050 LEVEL -
    2.82  2.96  3.06  3.13  3.18  3.23  3.27  3.30  3.33  3.35
    3.37  3.39  3.40  3.41  3.42  3.43  3.45  3.46  3.47

THE RANGES ABOVE ARE TABULAR VALUES.
THE VALUE ACTUALLY COMPARED WITH  MEAN(J)-MEAN(I) IS..
       92.3075 * RANGE * SQRT(1/N(I) + 1/N(J))

HOMOGENEOUS SUBSETS  (SUBSETS OF GROUPS, WHOSE HIGHEST AND LOWEST MEANS DO
NOT DIFFER BY MORE THAN THE SHORTEST SIGNFICANT RANGE FOR A
SUBSET OF THAT SIZE)


SUBSET  1

GROUP   GRP 20    GRP 19    GRP 18    GRP 17    GRP 16    GRP 15
MEAN 2348.0000 2357.2000 2360.6000 2439.0000 2441.2000 2457.2000

GROUP   GRP 14    GRP 13
MEAN 2477.4000 2487.8000
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
```

```
SUBSET  2

GROUP   GRP 19    GRP 18    GRP 17    GRP 16    GRP 15    GRP 14
MEAN 2357.2000 2360.6000 2439.0000 2441.2000 2457.2000 2477.4000

GROUP   GRP 13    GRP 12    GRP 11
MEAN 2487.8000 2543.2000 2547.2000
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

SUBSET  3

GROUP   GRP 17    GRP 16    GRP 15    GRP 14    GRP 13    GRP 12
MEAN 2439.0000 2441.2000 2457.2000 2477.4000 2487.8000 2543.2000

GROUP   GRP 11    GRP 10    GRP  8    GRP  9
MEAN 2547.2000 2554.4000 2627.0000 2628.0000
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

SUBSET  4

GROUP   GRP 15    GRP 14    GRP 13    GRP 12    GRP 11    GRP 10
MEAN 2457.2000 2477.4000 2487.8000 2543.2000 2547.2000 2554.4000

GROUP   GRP  8    GRP  9    GRP  7
MEAN 2627.0000 2628.0000 2637.8000
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

SUBSET  5

GROUP   GRP 14    GRP 13    GRP 12    GRP 11    GRP 10    GRP  8
MEAN 2477.4000 2487.8000 2543.2000 2547.2000 2554.4000 2627.0000

GROUP   GRP  9    GRP  7    GRP  6
MEAN 2628.0000 2637.8000 2666.8000
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
```

```
SUBSET  6

GROUP   GRP 12    GRP 11    GRP 10    GRP  8    GRP  9    GRP  7
MEAN 2543.2000 2547.2000 2554.4000 2627.0000 2628.0000 2637.8000

GROUP   GRP  6    GRP  5
MEAN 2666.8000 2712.2000
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

SUBSET  7

GROUP   GRP  8    GRP  9    GRP  7    GRP  6    GRP  5    GRP  4
MEAN 2627.0000 2628.0000 2637.8000 2666.8000 2712.2000 2750.8000
1PALLETS                              84/02/17. 13.02.32. PAGE    5


GROUP   GRP  3    GRP  2
MEAN 2754.2000 2781.6000
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

SUBSET  8

GROUP   GRP  5    GRP  4    GRP  3    GRP  2    GRP  1
MEAN 2712.2000 2750.8000 2754.2000 2781.6000 2863.6000
- - - - - - - - - - - - - - - - - - - - - - - - - - - -
```

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VITA

Captain Randall G. Johnson was born on 3 April 1954 in Fort Smith, Arkansas. He graduated from high school in Fort Smith in 1972 and attended the United States Air Force Academy from which he received a commission in the USAF and a degree of Bachelor of Science in Engineering Mechanics in June 1976. He completed pilot training and received his wings in July 1977. He then served as a C-130 pilot in the 32nd and 61st Tactical Airlift Squadrons, until entering the School of Engineering, Air Force Institute of Technology, in August 1982.

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ABSTRACT

This study developed a SLAM airfield model tailored for airlift operations. The model is formulated as a network and models loading, fueling, and maintenance of airlift aircraft. Only C-130, C-141, and C-5 aircraft can be considered.

The primary model inputs are aircraft input rates, and the availability of ramp space, maintenance team, load team, and k-loader resources. The output includes average ground-time, resource usage, and pallets airlifted from the airfield.

An experiment is made to identify a "best" strategy for aircraft input rates through a fixed airfield. The results show that any one of five input strategies out of 64 examined are of equal effectiveness.